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CHAPTER 46

The Effects of Chemical/Biological Protective Patient Wraps on Simulated Physiological Responses of Soldiers

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ABSTRACT

This study used a thermoregulatory model to examine the thermal burden imposed by a new U.S. Army protective patient wrap (PPW) design. The model simulations were conducted for typical desert, jungle, and temperate conditions with and without direct sun. Five PPW configurations (the current baseline, and laminated and non-laminated versions of the PPW with and without fan ventilation) were tested. The results suggested that soldiers would be likely to experience heat illness in < 6 hours when exposed to direct sun light in all simulated environments. Shade is effective in delaying or preventing soldiers from becoming heat casualties.

Keywords: Protective patient wraps, heat strain, modeling, simulation, core temperature, US Army, chemical/biological warfare, thermoregulation

INTRODUCTION

The protective patient wrap (PPW) is an encapsulating sleeping bag like portable, disposable and water-resistant material designed to protect injured soldiers, when necessary, from exposure to harmful chemical and biological materials during triage. It was developed by the US Army in 1980s when the use of chemical and biological weapons became more prominent (US Army Natick Soldier Center, 2007). After 2001, new PPW configurations were developed using more advanced technology. The purpose of this study was to evaluate new PPW designs for their possible thermal impact on soldiers, using a thermoregulatory model. Initial testing was done using a thermal manikin to measure the thermal and water vapor resistance of the PPW. Then the effects of new PPW configurations on patients' physiological responses were simulated for three types of hot climates (i.e., jungle, desert, temperate) with and without direct sun. A thermo-physiological model (Kraning and Gonzalez, 1997) utilized in this study uses first principles of physiology, heat transfer and thermodynamics and represents the human with six compartments (i.e., core, muscle, fat, vascular skin, avascular skin, and central blood). The model predicts physiologic responses over time (e.g., heart rates, core temperature (T_c)) of individuals as a function of metabolic heat production, anthropometry (i.e., height, weight, and percent body fat (%BF)), thermal aspects of the physical environment (i.e., air temperature (T_a), relative humidity (RH), mean radiant temperature (MRT), wind speed (WS)) and clothing characteristics (i.e., thermal and water vapor resistance), and physiological state (e.g., heat acclimatization, hydration).

This evaluation approach provides a convenient means of predicting thermal strain of workers without incurring the risk, cost and time associated with human studies. Predictive modeling is increasingly used as thermal injury prevention and occupational safety assessments.

METHODS

Model simulations to evaluate the different PPW configurations were conducted based on realistic model inputs. These inputs included: subject anthropometric information and resting metabolic rate, the thermal and water vapor resistances of the updated uniform and PPW configurations, and the ambient micro-weather conditions (temperature, humidity, solar load, wind speed). The triage patient was assumed to be heat acclimated with the height, weight, and %BF values (177 cm, 82 kg, 17%) of average active duty US Army male soldiers (Bathalon et al., 2004). The thermal and water vapor resistance characteristics of the current PPW, and the new laminated and non-laminated PPW designs, with and without battery powered fan ventilation, were measured with the USARIEM thermal sweating manikin (Figure 1). The manikin was dressed in T-shirt, Fire Resistant Army Combat Uniform (FR-ACU), and green wool socks, placed inside the PPW, and positioned

on a cot elevated two feet above the ground. The metabolic rate of the patient associated with the condition was estimated to be 0.8 MET (~45W/m^2) (ASHRAE, 2001). The simulation of human physiological responses to PPW encapsulation were conducted for typical desert (T_a: 49°C, RH: 20%), jungle (T_a: 35°C; RH: 70%) and temperate (T_a: 35°C; RH: 50%) conditions where deployed soldiers could experience heat related illness or impairment. The MRT for the shade or no-sun condition was assumed to equal the environment's T_a. For sunny environments, the MRT was estimated to be 36°F (20°C) greater than T_a, using the constant radiant load (175 W•m^{-2}) and radiant heat transfer coefficient, (Matthew et al., 2001). A constant WS of 0.4 m•s^{-1} (0.89 mph) was used for all simulations. Table 1 summarizes the details of three environmental conditions and their radiation levels for full sun (MRTs) and non-sun/shades (MRTn) conditions.

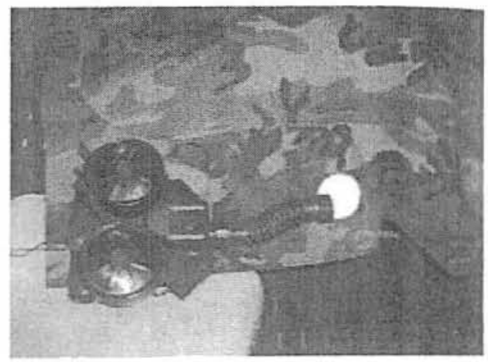


Figure 1. Photographs of the sweating-thermal manikin and protective patient wrap (PPW) test set-up. Left - Manikin placed inside the closed PPW. Right - the filtered ambient air ventilation system attached to the foot of the PPW.

Thirty model simulations were conducted based on the combinations of five PPW configurations and three environmental conditions with each environment in full sun and complete shade (30 = 5 x 3 x 2). Levels of physiological heat strain were assessed based on (1) T_c limit of 38.5°C, representing the point where approximately 25% heat casualty rate is expected to occur (Sawka et al., 2000) and (2) a six hour maximum encapsulation time for PPW in compliance with U.S. Army requirement (Department of the Army, 1985).

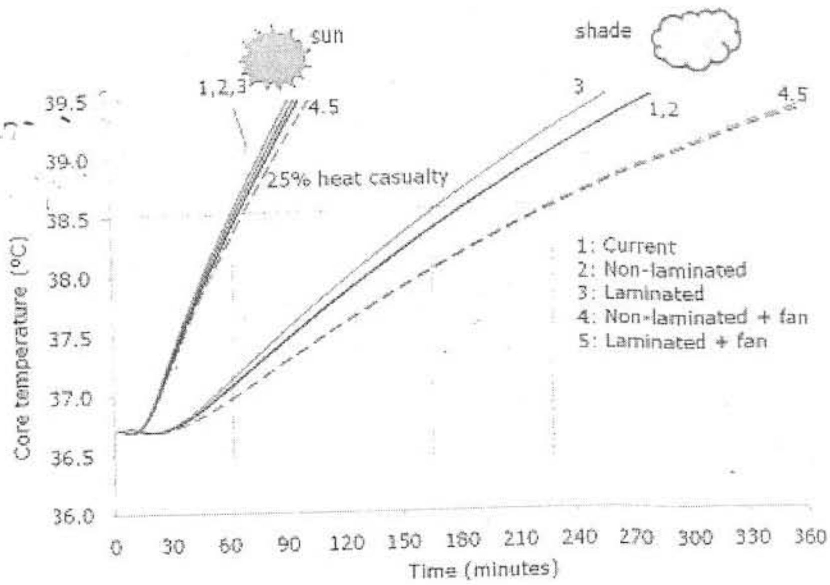
Table 1: Meteorological conditions used to simulate desert, jungle, and temperate environments.

	Environments		
Parameters	Desert	Jungle	Temperate
Ta °C(°F)	48.9 (120)	35.0 (95)	35.0 (95)
RH %	20	75	50
DP °C(°F)	20 (68)	30 (86)	23 (73)
V $m \bullet s^{-1}$ (mph)	0.4 (0.89)	0.4 (0.89)	0.4 (0.89)
MRTs °C(°F)	68.9 (156)	55.0 (131)	55.0 (131)
MRTn °C(°F)	48.9 (120)	35.0 (95)	35.0 (95)

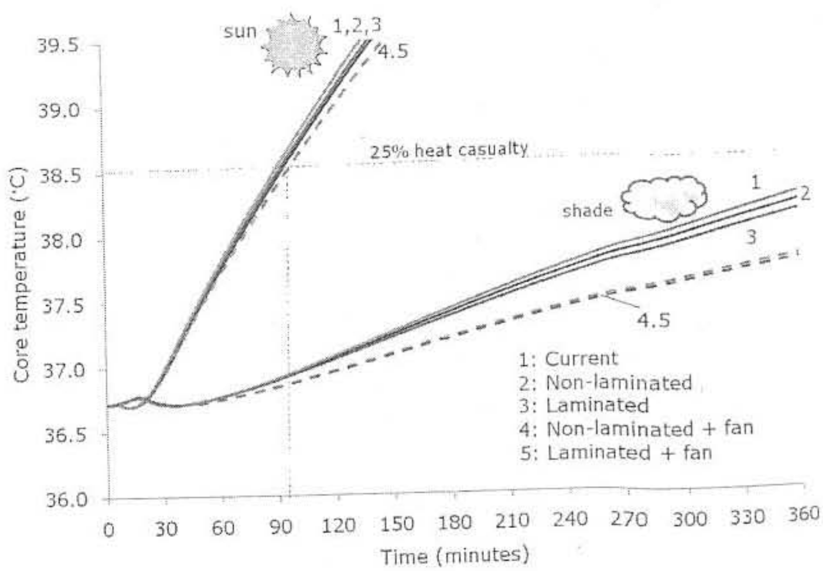
Ta: Air temperature, RH: Relative humidity; DP: Dew point; V: Wind speed; MRTs: Mean radiant temperature with full sun; MRTn: Mean radiant temperature with shade

RESULTS

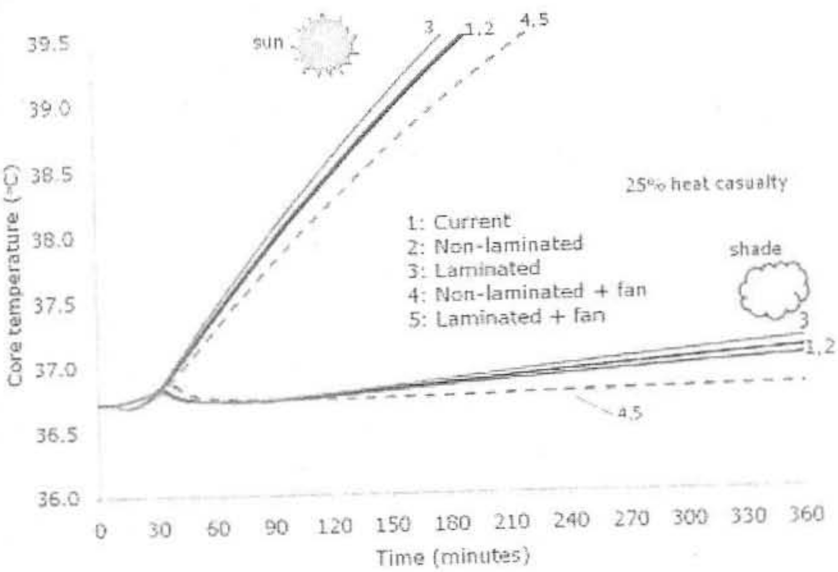
Figure 3a-c summarizes the simulated T_c responses to the different PPW configurations in the three environmental conditions with or without solar radiation. Overall, for the desert condition with and without solar radiation, T_c rises to 38.5 °C more quickly than other conditions. The simulations indicated that soldiers inside PPW would be likely to experience thermal strain (i.e., $T_c > 38.5$°C) during the 6hr exposure in all three climate conditions with the strain developing roughly 25 – 50% faster in the higher levels of T_a and/or RH. In all three environmental conditions, patients in all of the PPWs had consistently lower T_c levels when located in the shade and could safely stay longer than when located in the sun. When the simulated patients were located in a shaded desert or a sunny temperate condition, the fan-powered PPW ventilation system was very effective in helping individuals thermo-regulate, lowering their T_c responses and thus increasing PPW safe stay times by about 15-30% compared to the non-ventilated PPW configurations (Figure 3a, 3c). The differences in T_c responses among the PPWs were small in other conditions.



(a) Desert condition (48.9ºC/120ºF, 20%RH)



(b) Jungle condition (35ºC/95ºF, 75%RH)



(c) Temperate condition (35°C/95°F, 50%RH)

Figure 3. Core temperature responses over time for five protective patient wrap configurations (current, non-laminated, laminated, non-laminated + fan, laminated + fan) in sunny or shaded (a) desert, (b) jungle and (c) temperate environmental conditions. At a core temperature of 38.5 °C, a 25% heat casualty rate is expected.

Table 2 summarizes tolerance times based on the T_c limit of 38.5 °C by configuration and environmental conditions. Overall, high T_a, high RH, and solar radiation decreased tolerance times. Individuals are more tolerant of encapsulation in PPW in temperate weather than jungle, and least tolerant in the desert environment. Patients in shade are likely able to stay inside a PPW 3-4 times longer than when under direct sun. The model simulations also indicated that individuals would likely become heat casualties in less than 6 hours inside any of the PPW in direct sun. The simulated individuals could tolerate the PPWs for 6 hours only when T_a is equivalent to/less than 35 °C (e.g., temperate, jungle) and MRT is equivalent to/less than T_a. (e.g., shade condition). The use of a fan under sunny temperate and shaded desert conditions increased the estimated time to achieve a T_c limit of 38.5 °C by about 20 min. and 50 min, respectively. The fan had no significant effect under the other conditions.

Table 2: Tolerance time (minutes) to reach core temperature of 38.5°C by protective patient wrap configuration and environmental condition with or without solar load.

	Desert		Jungle		Temperate	
Configuration\Solar effect	Solar	Shade	Solar	Shade	Solar	Shade
Current	66	178	93	>360	124	>360
Non-Laminated + Fan-Off	64	177	91	>360	123	>360
Non-Laminated + Fan-On	68	223	96	>360	140	>360
Laminated + Fan-Off	62	164	90	>360	117	>360
Laminated + Fan-On	68	220	96	>360	139	>360

CONCLUSIONS

This study examined simulated T_c responses of heat acclimated soldiers who were fully encapsulated in a PPW during three different hot-warm environmental conditions. The simulations used to evaluate the different PPW configurations were based on realistic information regarding the subjects' anthropometrics, metabolic rate, PPW biophysical characteristics, and environmental and system operational conditions. The results indicated that patients inside PPW would be likely experience thermal strain faster when T_a and RH increase. Further, the simulations indicated that shading from direct sun is critically important in delaying or preventing individuals from becoming heat casualties. The fan-powered PPW ventilation system was effective only when they were lying under a shaded desert or sunny temperate condition. Otherwise, the differences in T_c responses among the PPWs were minimal. Based on the current U.S. Army criterion for PPW encapsulation targeted time (Department of Army, 1985), soldiers would be likely to experience heat illness in less than six hours when exposed to direct sun light in all simulated environments. Simulated patients, when shaded from solar exposure, could safely endure 6 hours only in the jungle and temperate environments. Thus, shade from direct sun is important in delaying and preventing patients from becoming heat casualties.

The simulation used in this study was assumed to be an "average uninjured" soldier in the US Army. The different somatic forms in a population as well as the patients' medical condition and treatment (Cadarette et al., 1988; Stephenson et al., 1988; Yokota et al., 2008; Bar-Or et al., 1969) could cause variability in physiological responses to the heat stress. For instance, obese individuals in walking in the heat responded to thermal strain with a more rapid rise in T_c than lean individuals (Bar-Or et al., 1969; Shvarts et al., 1973). A multivariate thermal

model simulation suggested similar results would be evident in soldiers walking and working on a simple Army task (Yokota et al., 2008). For another example, the usage of atropine as a common treatment to regulate patients' parasympathetic nervous system reduces their sweat rates, and rapidly increases a patient's T_c (Cadarette et al., 1998; Stephenson et al., 1988). Importantly, medical circumstances such as injury, loss of blood, and respiratory problems inside a PPW may also impact the tolerance time of a patient (Cadarette et al., 1998; Stephenson et al., 1988). Thus, thermal responses inside a PPW can vary across individuals.

This study demonstrated that the thermoregulatory model simulations can provide a useful insight into the thermal strain imposed on soldiers/patients encapsulated in PPW. The simulations may be useful not only in understanding the thermal benefits/disadvantage of various PPW prototypes but also assisting in a cost effectiveness analysis of prototype PPWs. The approach taken in this study to assessing the thermal impact on soldiers can be extended to other types of equipment (e.g., micro-climate cooling device, body armor, vehicles) and protective gear/clothing (e.g., body armor, Mission Oriented Protective Posture gear, battle dress uniform). Further, these types of simulations can be applied to various occupational populations other than military (e.g., firefighters, border patrol, police bomb squad) to assess the safety of workers who are exposed to thermal stress during their work.

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REFERENCES

ASHARE (2001), *ASHARE handbook fundamentals SI edition*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

Bar-Or, H., Lundegren, H., and Buskirk, E. (1969), "Heat tolerance of exercising obese and lean women." *Journal of Applied Physiology*, 26, 403-409.

Bathalon, G., McGraw, S., Friedl, K., et al. (2004), *Rationale and evidence supporting changes to the Army weight control program*. Technical Report T04-08, USARIEM, Natick.

Cadarette, B., Speckman, K., Stephenson, L. (1988), "Physiological assessments of chemical threat protective patient wraps in three environment." *Military Medicine*, 153, 166-179.

Department of the Army (1985), *Letter Requirement (LR) Chemical Warfare Agent Protective Patient Wrap* (USATRADOC CAN 21318). Academy of Health Science. September 18, Fort Sam Houston.

Kraning, K., and Gonzalez, R.(1997), "A mechanistic computer simulation of human work in heat that accounts for physical and physiological effects of clothing, aerobic fitness, and progressive dehydration." *Journal of Thermal Biology,* 22,331-342.

Matthew, W., Santee, W., and Berglund L. (2001), *Solar load inputs for USARIEM thermal strain models and the solar radiation-sensitive components of the WBGT index.* Technical Report T01-13, USARIEM, Natick.

Sawka, M., Latzka, W., Montain, S. et al. (2000), "Physiologic tolerance to uncompensable heat: intermittent exercise, field vs. laboratory." *Medicine & Science in Sports & Exercise,* 33, 422-430.

Shvarts, E., Sarr, E., and Benor, D. (1973), "Physique and heat tolerance in hot-dry and hot-humid environments." *Journal of Applied Physiology* 34,799-803.

Stephenson, L., Kolka, M., Allan, A. et al. (1988), "Heat exchange during encapsulation in a chemical warfare agent protective patient wrap in four hot environments." *Aviation, Space and Environmental Medicine*, 59, 345-351.

US Army Natick Soldier Center (2007) *Chemical protective patient wrap program* [CD]. US Army Natick Soldier Center. Natick, MA.

Yokota, M., Bathalon, G., and Berglund, L. (2008), "Assessment of male anthropometric trends and effects on simulated heat stress responses." *European Journal of Applied Physiology*, 104,297-302.